CLAIMS

1. A spring surface treatment method, comprising the steps of:

(A) nitriding surface layer of springs;

(B) projecting hard metal particles having hardness which is lower than the hardness of the nitrided outermost surface layer (micro-Vickers hardness at a depth of about 5 µm from the outermost surface) and is in the range of Hv 500 to 800 and diameters from 200 to 900 µm against the nitrided surface of the springs at velocity from 40 m/sec. to 90 m/sec., so as to prevent generation of a microcrack in the surface layer by the projection (shot peening) and provide compression residual stress comparatively deep inside the springs; and

(C) projecting a number of fine metal particles having a mean diameter of all particles of 80 µm or less, a mean diameter of each particle in the range between 10 µm inclusive and less than 100 µm, a spherical or near spherical shape having no square portions, specific gravity from 7.0 to 9.0, and hardness which falls in the range between Hv 600 and Hv 1100 inclusive and is equal to or less than the hardness of the outermost surface layer of the springs after nitriding or low-temperature carbonitriding at velocity from 50 to 190 m/sec., while controlling an instantaneous temperature rise limit of the iron matrix (excluding the nitride compound layer) of the nitrided

spring surface layer due to collision to be low enough to cause work hardening in the spring surface layer but not to cause softening due to recovery/recrystallization, thereby effectively work hardening and preventing generation of any microcracks in the surface layer to provide high compression residual stress and hardness.

2. A spring surface treatment method, comprising the steps of:

(A) projecting a number of metal particles such as iron-based particles having diameters between 10 μm inclusive and less than 100 μm, a mean diameter of all particles of 80 μm or less, more desirably 65 μm or less, mean diameter of each particle of 10 to 80 μm, a spherical or near spherical shape having no square portions, a specific gravity of 7.0 to 9.0, and a hardness of Hv 350 to 900 against the surface of springs before nitriding at collision velocity in the range of 50 m/sec. and 160 m/sec. inclusive so that a temperature rise limit of the surface of the spring due to collision is controlled to be low enough to cause work hardening of the iron matrix of the springs but lower than the point at which recovery/recrystallization may occur so as to prevent generation of any microcracks and the like;

(B) nitriding surface portion of the springs after the step (A);

(C) projecting hard metal particles having hardness which is lower than the hardness of the nitrided outermost surface layer (the micro-Vickers hardness at a depth of about 5 µm from the outermost surface) and in the range of Hv 500 to 800, and a grain diameter of 200 to 900 µm against the nitrided surface of the springs at velocity of 40 m/sec. to 90 m/sec., so as to prevent generation of any microcracks in the surface layer by the projection (shot peening) and provide compression residual stress comparatively deep inside each spring; and

(D) projecting a number of metal microparticles having a mean diameter of all particles of 80 µm or less, a mean diameter of each particle in the range between 10 µm inclusive and less than 100 µm, a spherical or near spherical shape with no square portions, a specific gravity of 7.0 to 9.0, and a hardness which falls in the range between Hv 600 and Hv 1100 inclusive and is equal to or less than the hardness of the outermost surface layer of the spring after nitriding or low-temperature carbonitriding at the velocity of 50 to 190 m/sec., while controlling the instantaneous temperature rise limit of the iron matrix (excluding nitride compound layer) of the nitrided spring surface layer due to collision to be high enough to cause work hardening in the surface layer but lower than a point at which softening due to recovery/recrystallization may occur, thereby effectively causing work hardening and

preventing generation of any microcracks in the surface layer to provide a high compression residual stress and hardness.

3. A surface treatment method comprised of the step of bombarding hard metal particles having hardness in the range between Hv 350 and 1100, specific gravity of 7.0 to 9.0, a mean diameter of all particles of 80 μm or less, a mean diameter of each particle in the range between 10 μm inclusive and less than 100 μm, and a spherical or near spherical shape with no square portions, on the surface of springs with the surface layer hardness of Hv 400 to 750, which hardness was obtained either by low-temperature annealing for removal of macroscopic residual stress after cold forming, quench and temper after cold forming, or quench and temper after hot forming, at the collision velocity of 50 m/sec to 160 m/sec, while controlling the temperature rise limit of the spring surface layer due to collision to be low enough to cause work hardening in the spring surface layer but not to cause softening due to recovery/recrystallization and preventing generation of any microcracks in the surface layer and the like which may deteriorate fatigue strength, thereby improving the hardness and compression residual stress of the surface layer which is 30 μm to 50 μm or less deep from the surface and resulting in improved endurance of the springs.

4. A spring surface treatment method for preventing generation of harmful microcracks in surface layer and the like which may deteriorate fatigue strength and for improving especially the hardness and compression residual stress of the surface layer which is 30 μm to 50 μm or less deep from the surface, to improve endurance of the springs, the method comprising the steps of:

(A) projecting hard metal particles having hardness of Hv 350 to 900 and the particle diameter of 200 to 900 μm against the surface of formed and tempered springs having hardness of the surface layer of Hv 400 to 750 at the velocity of 40 m/sec to 90 m/sec so as to prevent generation of harmful microcracks in the surface layer and provide compression residual stress comparatively deep inside the springs; and

(B) performing the surface treatment method according to claim 3 on the spring surface after the step (A).

5. A spring surface treatment method according to claim 1 or 2, wherein the particles having a mean diameter of all particles of 80 μm or less and a mean diameter of each particle in the range between 10 μm inclusive and less than 100 μm and the projection conditions of the particles are limited to the following:

hardness of projected particles: initial hardness (new particles) Hv 600 to 1100

size of projected particles: initial mean diameter of each particle (new particle) 10 μm to 80 μm

mean diameter of all particles: 65 μm or less

specific gravity of projected particles : 7.0 to 9.0

collision velocity against spring: 60 m/sec. to 140 m/sec.

6. A spring surface treatment method according to claim 3 or 4, wherein the particles having a mean diameter of all particles of 80 μm or less and a mean diameter of each particle in the range between 10 μm inclusive and less than 100 μm and the projection conditions of the particles are limited to the following:

hardness of projected particles: initial hardness (new particles) Hv 350 to 1100

size of projected particles: initial mean diameter of each particle (new particle) 10 μm to 80 μm

mean diameter of all particles: 65 μm or less

specific gravity of projected particles: 7.0 to 9.0

collision velocity against spring: 60 m/sec. to 140 m/sec.

7. A spring surface treatment method according to claim 1 or 4, wherein in the step (B) of claim 1 or in the step (A) of claim 4, the projection of the hard metal particles having a diameter of 0.2 to 0.9 mm is divided into first-stage projection of comparatively large particles having a diameter of 0.5 to 0.9 mm and second-stage projection of

comparatively small particles having a diameter of 0.2 to 0.4 mm.

8. A spring produced from a circular cross-section wire or a non-circular cross-section wire by the steps according to claim 1 as essential steps, the spring being a coil spring made of any of steel types (1) to (4) containing respective chemical components, a compression residual stress of iron in a near surface layer by X-ray method being greater than 1700 MPa, sizes of a hard nonmetallic inclusion, carbide, carbonitride, nitride, and the like which may cause fatigue breaking of the spring and the hardness of matrix satisfying following X or Y, the spring being a high fatigue resistance strength spring having a fatigue strength at 5×10^7 times of repetition satisfying expression (1) below:

in a repeated stress of $\tau m \pm \tau a$, when $\tau m = 800 - x$, $\tau a \geq (620 + x/5)$ ... (1)

where τm: mean stress,

τa: amplitude stress, and

x: variable in the range of 0 and 150 inclusive,

(unit: all MPa),

X: controlling the hardness of the matrix at a depth in the range of 0.2 mm to 0.5 mm inclusive from the spring surface in the range between Hv 520 and 580 inclusive when the size of a harmful nonmetallic inclusion, carbide, and the like existing in the spring is less than 20 µm or 15 µm or less,

Y: controlling the hardness of the matrix at a depth in the range of 0.2 mm to 0.5 mm inclusive from the spring surface in the range between Hv 520 and 630 inclusive when the size of a harmful nonmetallic inclusion, carbide, and the like existing in the spring can be controlled to 10 μm or less,

the steel types (1) to (4) being as follows:

(1) a steel type containing as essential components C: 0.50 to 0.80%, Si: 1.20 to 2.5%, Mn: ≤1.20%, and Cr: ≤1.80% and iron and impurities as the remainder, including a steel type with one or two kinds of V: 0.03 to 0.60% and/or Nb: 0.02 to 0.20% added thereto;

(2) a steel type containing one or more kinds of Ni: 0.5% or less and/or Co: 3.0% or less in addition to the steel type (1);

(3) a steel type containing W: 0.5% or less and/or Mo: 0.6% or less and/or Al: 0.5% or less in addition to the steel type (1) or (2); and

(4) a steel type containing C: 0.05% or less, Si: 0.8% or less, Mn: 0.8% or less, Ni: 16 to 26%, Ti: 0.2 to 1.6%, Al: 0.4% or less, Co: 8.5% or less, Mo: 5.5% or less, Nb: 0.6% or less (in addition to the above, 0.1% or less of B, Zr, and/or Ca may be added), and unavoidable impurities and iron as the remainder (unit of the chemical components is all mass percent).

9. A steel spring excellent in fatigue strength, produced using any of the steel types (1) to (3) in claim 8, by

quenching and tempering, so as to have a higher tensile strength than a JIS SWOSC-V oil tempered wire for valve springs depending on the wire diameter, forming into a spring, and then annealing at low temperature for removal of its residual stress, or by quenching and tempering after spring formation so as to have a higher tensile strength or hardness than a JIS SWOSC-V oil tempered wire for valve springs, or produced using the steel type (4) in claim 8 by performing solution treatment, cold wiredrawing or rolling, forming into a spring, aging, and quality-adjusting so that the tensile strength be 1900 MPa or more, being followed by the steps according to claim 4, wherein the spring has residual stress near the surface layer in the range between more than 1100 Mpa and 1700 MPa inclusive, the surface hardness is in the range of Hv 600 and Hv 800 inclusive, and when the hardness at a depth of 0.2 mm to 0.5 mm from the surface is in the range of Hv 580 to 630, the size of nonmetallic inclusions are less than 10 μm or less, and when the hardness at a depth of 0.2 mm to 0.5 mm from the surface is in the range between Hv 520 inclusive and less than Hv 580, the size of nonmetallic inclusions are 15 μm or less or less than 20 μm.

10. A spring according to claim 9, wherein the fatigue limit of the spring satisfies the following:

At a repeated stress of $\tau m \pm \tau a$, and 5×10^7 times of repetition,

$\tau a \geq 470 + x/5$ ... (2)

when $\tau m = 690 - x$,

where x: 0 to 183, and unit: MPa.

11. A spring made of cold drawn or warm drawn piano wire, low-alloy steel wire for spring superior in warm creep resistance to the piano wire, or similar steel wire, mainly composed of fine pearlite structure, having the wire diameter in the case of circular cross-section wire, the mean diameter or the mean thickness in the case of the non-circular cross-section wire of 1.5 mm or more, produced by subjecting to low temperature annealing for removal of the residual stress after forming into a spring, projecting hard metal particles having diameter of 0.2 to 0.9 mm, and then projecting a number of fine metal particles having a mean diameter of all particles of 65 μm or less, a mean diameter of each particle of 10 to 80 μm, spherical or near spherical shape having no square portions, specific gravity of 7.0 to 9.0, and hardness in the range of Hv 350 and 1100 inclusive at velocity of 50 to 160 m/sec, while controlling temperature to be low enough to cause work hardening in the near surface layer but not to cause recovery/recrystallization, and having compression residual stress of 550 MPa or more in the iron matrix of the surface layer by X-ray method and a fatigue limit of:

At a repeated stress of $\tau m \pm \tau a$, and 5×10^7 times of repetition,

$\tau a \geq 422 + x/5$ ... (3)

when $\tau m = 690 - x$,

where, unit: MPa, and x: 0 to 140.

12. A spring made of a normal JIS SWOSC-V oil tempered wire for valve springs produced by subjecting to low-temperature annealing for removal of residual stress after formation into a spring, projecting hard metal particles having diameter of 0.2 to 0.9 mm, and then projecting a number of fine metal particles having a mean diameter of all particles of 65 μm or less, a mean diameter of each particle of 10 to 80 μm, a spherical or near spherical shape having no square portions, a specific gravity of 7.0 to 9.0, and a hardness in the range of Hv 500 and 1100 inclusive at a velocity of 50 to 160 m/sec. while controlling a temperature to be low enough to cause work hardening in the near surface layer but not to cause recovery/recrystallization, to obtain compression residual stress measured by X-ray method of 900 MPa or more in the near surface layer, hardness at the depth of 0.2 to 0.5 mm from the surface of Hv 520 to 600, sizes of nonmetallic inclusions of 15 μm or less, and the fatigue limit of:

At a repeated stress of $\tau m \pm \tau a$, and 5×10^7 times of repetition,

$\tau a \geq 440 + x/5$ ... (4)

when $\tau m = 690 - x$,

where, unit: MPa, and x: 0 to 208.

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13. A sheet spring or wire spring with excellent fatigue strength, of which hardness at the surface layer before shot-peening is Hv 400 to 750, obtained by being projected by metal particles, each of which is characterized by the hardness of Hv 350 to 1100, the mean diameter of 10 to 80 μm, spherical or near spherical shape with no square portions and a specific gravity of 7.0 to 9.0, with the mean diameter of the largest particle and the mean diameter of all particles to be 80 μm and 65 μm, respectively and preferably 75 μm and 50 μm, respectively, at a collision velocity of 50 to 160 m/sec while controlling the projection so as to cause work hardening but not to cause recovery/recrystallization.

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